Pathogens & Nutrients

Summary

Human and animal wastes carry pathogenic organisms, such as bacteria and viruses, and are also rich in nutrients. Although pathogens and nutrients are natural components of the Puget Sound ecosystem, human development, industrialization and population of watersheds and shorelines contributes increased loadings of these materials to the waters of the Puget Sound basin. Where these increased loadings occur, pathogens and nutrients exist in such high concentrations that they effectively become contaminants that can cause significant water quality problems. Pathogens can affect human health when people come in direct contact with them or eat fish or shellfish harvested from contaminated areas.

Pathogen- and nutrient-related water quality problems typically occur in the vicinity of contamination sources. Pathogen and nutrient contamination is a significant concern in a number of locations around Puget Sound, especially in important shellfish growing areas, near the mouths of major rivers and in bays and inlets where circulation is limited.

It is difficult to discern trends in Puget Sound's pathogen and nutrient contamination over time because measurements are quite variable in time and space, but, there is evidence that conditions may be worsening in some locations. For example:

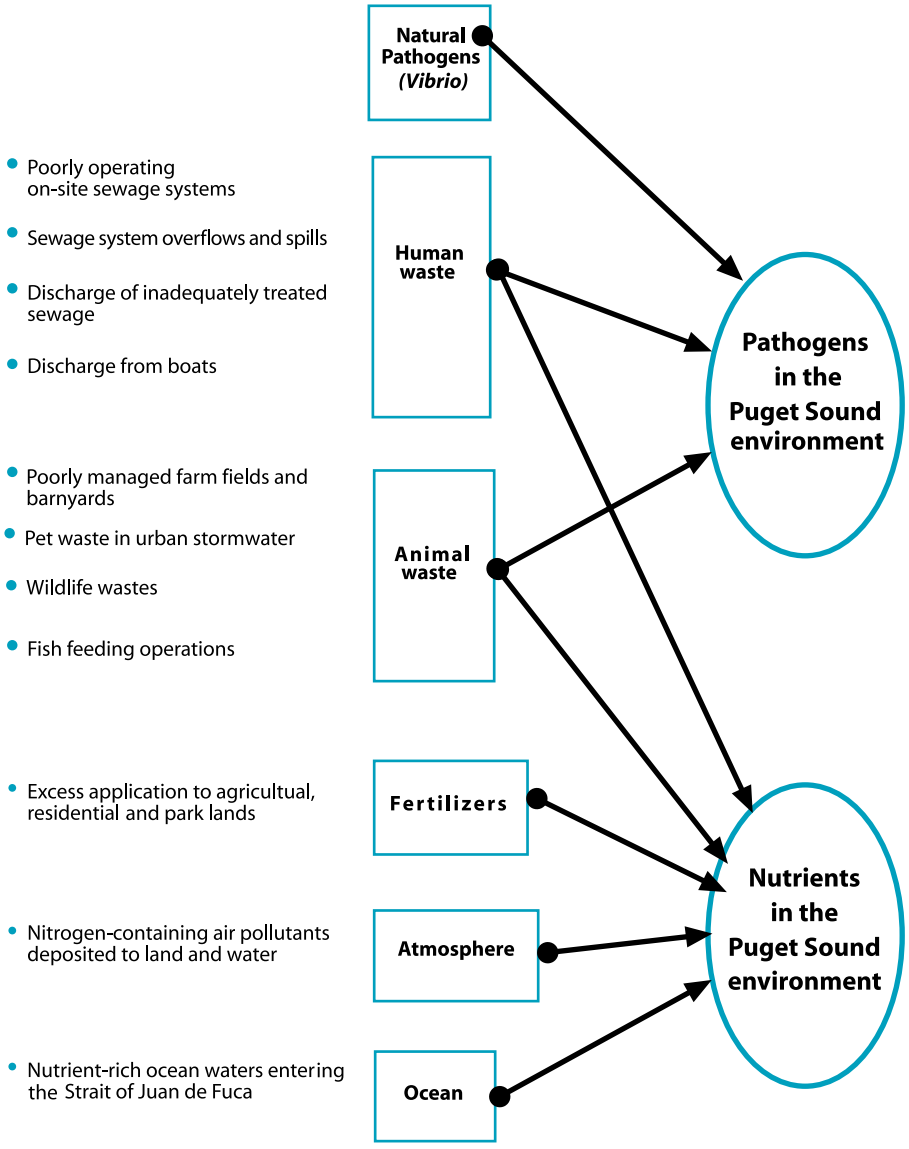
- Fecal contamination at Burley Lagoon (at the head of Carr Inlet) and Henderson Inlet seems to have increased in recent years.

- In Hood Canal, a zone with a low concentration of dissolved oxygen seems to persist through more of the year than it did in years past. Whether this indicates water quality degradation associated with nutrient additions is not known.

At other locations, specifically the shellfish-growing areas in south Puget Sound's Oakland Bay and Eld Inlet, conditions appear to be improving. Fecal contamination in these two areas decreased through the 1990s, probably reflecting considerable public and private work to address point and nonpoint sources of pollution.

Concerns About Pathogen and Nutrient Contamination of Puget Sound. Many human activities in watersheds and on shorelines allow contaminants from human and animal wastes to cause problems in Puget Sound's waters. Figure 18 depicts the major sources of pathogens and nutrients to Puget Sound. Many of these sources are related to human and animal wastes and carry both pathogens and nutrients. Some nutrient sources, particularly lawn fertilizers, atmospheric deposition and the Pacific Ocean, do not carry pathogens.

Figure 18. Sources of nutrients and pathogens to Puget Sound.



Many pathogenic organisms, including bacteria, viruses and protozoans, can survive outside of their animal hosts in aquatic environments. As a consequence, humans and other animals that ingest water or seafood from contaminated areas are at risk of contracting diseases caused by these pathogens. Human diseases associated with waterborne pathogens include typhoid, cholera and hepatitis. Pathogens may also threaten wild and domestic animals in a number of ways.

An excessive loading of nutrients, known as eutrophication, does not typically cause direct harm to a body of water. Instead, when conditions are favorable (i.e., when the water column is stratified, as discussed on pages 20-21, excess nutrients can increase the productivity of algae and plants. Increased productivity can alter the marine ecosystem by shifting the balance in plant and animal communities. Increased productivity can also cause water quality problems when the organic matter decays and depletes dissolved oxygen in the water. Excess nutrient-loading into waters that are stratified or otherwise poorly circulated can lead to nutrient-related water quality problems. Figure 19 summarizes some of the potential effects of eutrophication in Puget Sound.

Control of Pathogen and Nutrient Contamination in Puget Sound. The *Puget Sound Water Quality Management Plan* addresses concerns about pathogen and nutrient contamination through a variety of programs. The plan's attention to on-site sewage systems and shellfish protection is primarily driven by concerns about pathogen contamination from fecal matter. Plan programs related to agricultural and forest practices and municipal and industrial discharges address the spectrum of contaminants associated with these stresses, including both pathogens and nutrients.

Wastewater treatment, proper operation and maintenance of on-site sewage systems, and best management practices for agricultural and forest lands have all contributed

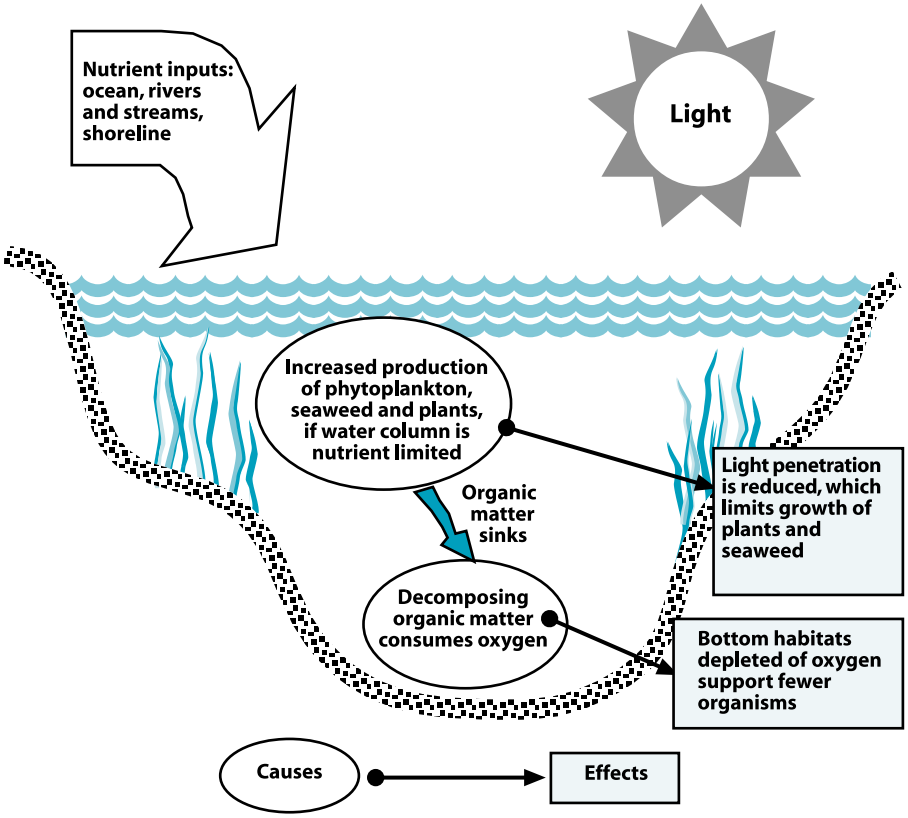


Figure 19. Potential effects of eutrophication in areas of Puget Sound with limited vertical circulation.

to the ongoing control of nutrient and pathogen contamination in Puget Sound. See pages 38-40 for a discussion of water quality improvements (and shellfish growing area upgrades) related to the successful control of fecal contamination at some locations.

Problems persist, however, because sources have not always been effectively controlled and controls (including repair of on-site sewage systems and use of best management practices in barnyards) have not always been adequately maintained. For example, fecal contamination increased recently in the late 1990s at Burley Lagoon, at the north end of Carr Inlet, despite corrective actions along the shoreline and in the watershed. Effective control of fecal contamination at Burley Lagoon will apparently require better controls, broader implementation of controls and continued maintenance of practices that protect water quality. Additional stresses are continually placed on the watershed by human population growth of up to two percent per year in Kitsap and Pierce counties.

In some cases, nutrient loadings can be reduced independently of controls on fecal contamination. For example, nutrient concentrations in the effluent from the Lacey-Olympia-Tumwater-Thurston County wastewater treatment plant were reduced 88 percent following the advent of nitrogen removal treatment processes at the plant (Eisner and Newton, 1997). Landowners and landscapers can control potential nutrient additions to nearby waters by maintaining vegetated buffers, reducing or improving application of fertilizers, or instituting other best management practices on residential, commercial, agricultural and park lands.

Findings on Pathogens

Waters polluted by human and animal wastes may contain a great diversity of pathogenic organisms. Rather than attempt to monitor all the various pathogens (most of which occur in very low concentrations and are costly and difficult to treat), scientists typically look for the presence of waterborne pathogens by measuring concentrations of fecal coliform bacteria. Organisms identified as fecal coliform bacteria occur predominantly in the gut of warm-blooded animals, and are carried into the environment in the fecal matter of these animals. Fecal coliform bacteria are not usually harmful, but they do demonstrate the presence of fecal contamination; thus, fecal coliform bacteria are used to indicate the possibility that other pathogenic organisms are present.

Fecal contamination is a widespread problem in the Puget Sound basin. Rivers, streams, shellfish growing areas and open marine waters are affected by fecal contamination. Table 3 summarizes the number of fresh and marine water areas in the various river basins of the Puget Sound region identified by the Department of Ecology as impaired by fecal contamination (i.e., where water quality does not meet the state's standard for fecal coliform contamination). Fecal contamination is the most common water quality impairment in the Puget Sound basin; nearly one-half of all Puget Sound basin waters that have been assessed are affected. Thirty-two marine areas are among the more than 260 bodies of water in the Puget Sound basin identified as impaired by fecal contamination.

Rivers and Streams

As part of the PSAMP, Ecology monitors conditions monthly at 24 river and stream sampling stations throughout the Puget Sound basin. Figure 20 shows the degree of fecal contamination measured at these stations over the past five years. Specifically, the chart shows that for each year from 1995 through 1999, 40 to 80 percent of the monitoring stations experienced fecal coliform bacteria concentrations above Washington's water quality standard for fecal contamination at least once during the year.

WRIA number – Basin name	Number of fresh waters impaired by fecal coliform bacteria	Number of marine waters impaired by fecal coliform bacteria	Number of fresh waters impaired by ammonia or other forms of nitrogen	Number of marine waters impaired by ammonia or other forms of nitrogen	Number of fresh waters impaired by phosphorus	Total number of water-bodies in basin
1 – Nooksack	37	4	2			67
2 – San Juan		1				5
3 – Lower Skagit/Samish	11	4			2	42
4 – Upper Skagit						6
5 – Stillaguamish	14	1	2		1	34
6 – Island		2				6
7 – Snohomish	17				2	48
8 – Cedar/Sammamish	35				4	61
9 – Duwamish/Green	30	2	1	1	2	51
10 – Puyallup/White	14	1	1			33
11 – Nisqually	3	1			4	10
12 – Chambers/Clover	7				3	15
13 – Deschutes	11	2			1	27
14 – Kennedy/Goldsborough	8	5				22
15 – Kitsap	36	7			1	73
16 – Skokomish/Dosewallips	5	1				8
17 – Quilcene/Snow	3	1				20
18 – Elwha/Dungeness	4					9
19 – Lyre/Hoko						8
Total for Puget Sound basin	**235**	**32**	**6**	**1**	**20**	**545**

"Impaired" indicates that the body of water does not meet the applicable state water quality standard.

Source: Department of Ecology unpublished data.

Table 3. Numbers of fresh and marine waters in various Puget Sound basin Water Resource Inventory Areas (WRIAs) identified by the Department of Ecology as impaired by pathogens and nutrients: fecal coliform bacteria, ammonia or total nitrogen, and total phosphorus.

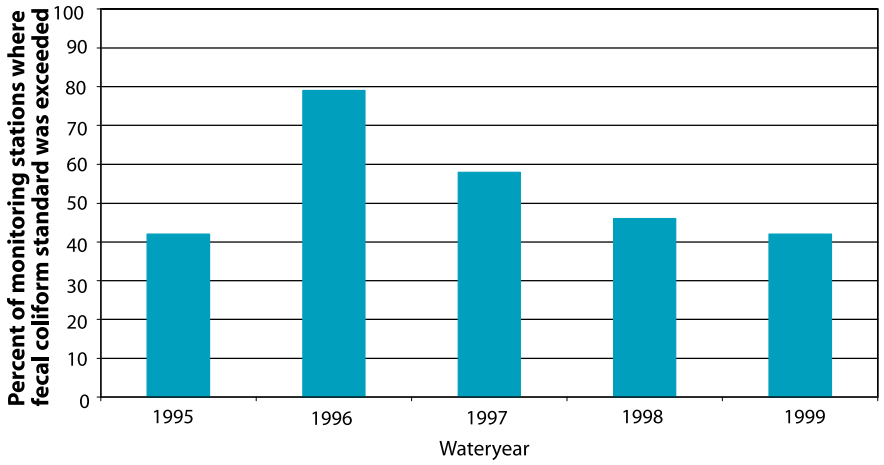


Figure 20. Puget Sound river and stream stations exceeding water quality standards for fecal coliform bacteria.

Because many pathways by which fecal contamination can reach rivers and streams involve rainwater runoff from lands where animal and human wastes are managed, we expect higher levels of fecal contamination when precipitation is higher. In fact, the Department of Health closes eight Puget Sound shellfish-growing areas to harvesting when specified amounts of rainfall occur. Higher than normal precipitation might partly explain the high incidence of fecal contamination observed in wateryears 1996 and 1997, when total precipitation and river flows were higher than average. However, wateryear 1999 was also much wetter than normal but the incidence of fecal contamination was not different from years with average or less than average amounts of precipitation, such as 1998 and 1995, respectively. These results indicate that additional analysis is needed to explain the occurrence of fecal contamination in Puget Sound's rivers and streams.

Department of Ecology Monitoring of Open Marine Waters

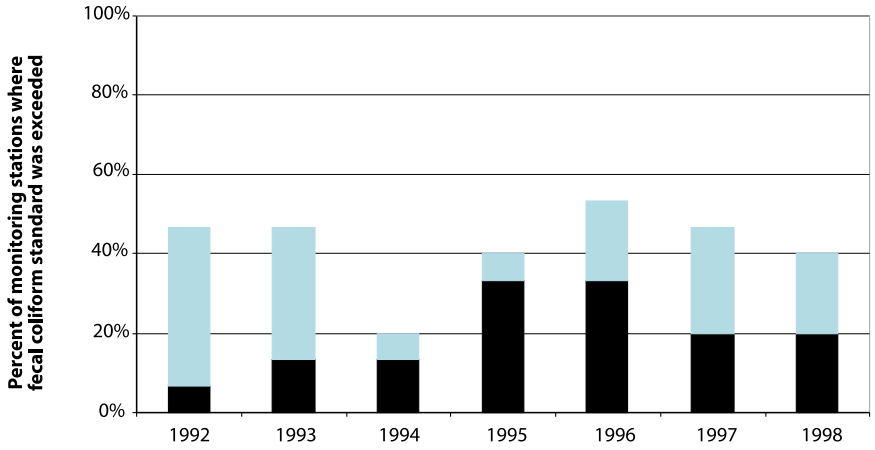
Results from Ecology's routine monitoring at 15 marine water stations as part of the PSAMP indicate that seven to 30 percent of stations had fecal coliform bacteria counts higher than the state's water quality standard for marine waters (43 colonies/100 ml). Depending on the year, an additional seven to 40 percent of monitoring stations show moderate levels of contamination—counts above 14 colonies/100 ml, the average level allowed in the standard.

Figure 21 shows the percentage of Ecology's marine water monitoring stations where measurements exceeded these fecal coliform concentrations in each wateryear from 1992 through 1998. Among these years, fecal coliform contamination was worst in 1995 and 1996, when one-third of the monitoring stations recorded concentrations above 43 colonies/100 ml. This data set reveals no trends in fecal contamination of Puget Sound's marine waters and no clear relationship to year-to-year variations in precipitation or stream flow.

Figure 22 shows the geographic distribution of fecal contamination among the Puget Sound marine water monitoring stations sampled by Ecology in wateryears 1996 and 1997. High fecal coliform bacteria levels were observed at a number of locations:

- Commencement Bay Near Browns Point (Tacoma) had multiple incidents of very high counts. These results are consistent with previous findings at another Commencement Bay station nearer the mouth of the Thea Foss Waterway.

Figure 21. Puget Sound marine monitoring stations exceeding water quality standards for fecal coliform bacteria.



- Inner Budd Inlet (Olympia) showed consistently high fecal coliform bacteria counts in 1996. This location is not sampled every year by Ecology scientists; conditions there were not monitored in 1997. The station nearer the middle of Budd Inlet had much lower concentrations. This difference in conditions illustrates the short marine lifetime of fecal coliform bacteria, as surface waters move from inner Budd Inlet out toward Puget Sound. It also demonstrates the low probability of detecting fecal coliform bacteria in open-water sites.
- Elliott Bay and the Main Basin of Puget Sound off of West Point (Seattle) occasionally show high counts of fecal coliform bacteria during winter months. These occasional high counts have been observed since 1993 and may be related to fresh water discharges from the Duwamish River and the Lake Washington Ship Canal.

Similar information to that in Figure 22 was presented in the *1998 Puget Sound Update* for wateryears 1990 through 1995. The results show high counts (above 43 colonies/100 ml) at many of the stations previously identified as having high fecal contamination. The two versions of this graphic cannot be directly compared, though, because monitoring is not completely consistent from year to year. Ecology scientists monitor a number of core stations every year and monitor other stations less frequently. The stations that are monitored less than annually are referred to as rotating stations. They are monitored as appropriate based on consideration of previous results, public concerns and a three-year cycle of emphasis between north, central and south Sound stations. A station in Drayton Harbor was first monitored by Ecology's ambient marine monitoring program during 1997 in response to concern over water quality in the inner harbor; high fecal coliform counts were observed. Liberty Bay and Commencement Bay near the Thea Foss Waterway had high counts in the past, but were not monitored in 1996 and 1997.

Moderate contamination (greater than 14 colonies/100 ml but less than 43 colonies/100 ml) was recently identified in the open waters of lower Hood Canal (beyond the Great Bend), where considerable development has occurred in recent years; all measurements at this station prior to 1996 showed low levels of fecal contamination.

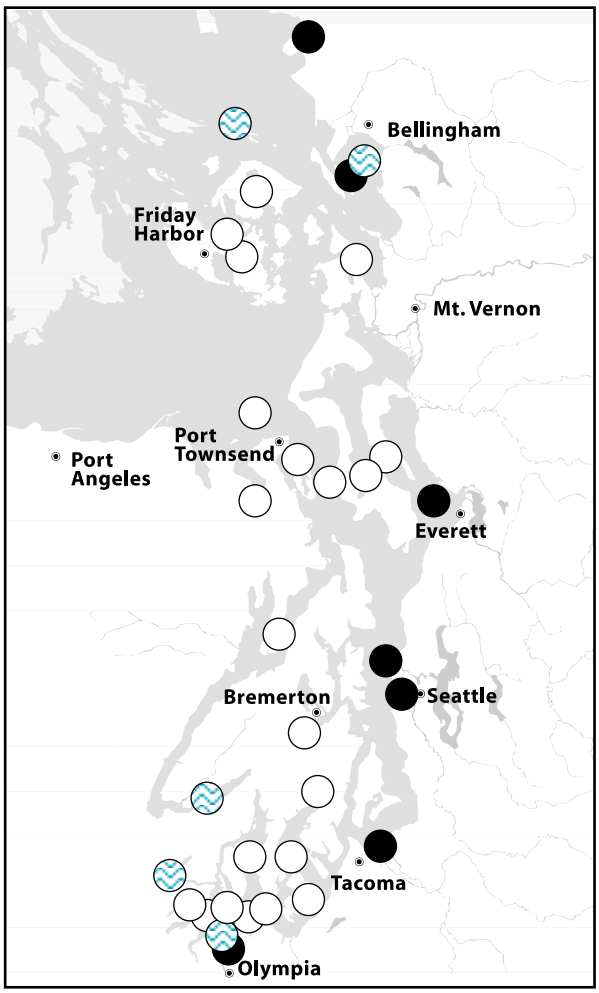


Figure 22. Distribution of fecal contamination at Ecology's open-water monitoring stations in Puget Sound, wateryears 1996-1997.

High (> 43 colonies/100 ml) at least once

Moderate (between 14 and 43 colonies/100 ml) at least once

Always low (< 14 colonies/100 ml)

Fecal contamination occurs in other areas of Puget Sound; not all areas of Puget Sound are monitored by Ecology, and their stations do not reflect worst-case conditions along shorelines and at the heads of bays and inlets.

Fecal coliform counts showing above moderate contamination in the early 1990s at Sinclair Inlet, Oakland Bay and outer Budd Inlet were not repeated during 1996 and 1997 when only low levels of contamination were observed. Previous records of moderate fecal contamination in south Puget Sound at Totten, Eld and Carr inlets were not repeated in samples taken in 1996 and 1997. This variability in observations may represent normal year-to-year variations.

Fecal Contamination at Offshore and Nearshore Areas of King County

The King County Department of Natural Resources monitored 15 nearshore and five offshore sites in central Puget Sound for fecal coliform and *Enterococcus* bacteria in 1997, and 20 nearshore and 10 offshore sites in 1998. The sites were located between Fauntleroy Cove and Richmond Beach, with most sites located on the east side of the Sound's Main Basin. Stations were centered near the county's two main wastewater treatment plant outfalls as well as in areas not influenced by wastewater discharges.

Sampling at offshore stations showed that both fecal coliform and *Enterococcus* bacteria levels were low, if detected at all, throughout the year for all stations with the exception of the station located in inner Elliott Bay. This station has consistently failed the applicable Washington state marine surface water standards for fecal coliform bacteria for the past several years. It is located near a combined sewer overflow (CSO) outfall and high bacteria counts are seen coinciding with high rainfall months (November through January). Currently, there are efforts to reduce the amount of CSO discharge at this site.

Water quality in Puget Sound's nearshore areas is greatly affected by rainwater runoff. Consequently, the highest bacteria counts at nearshore monitoring stations are typically found when there has been a significant amount of rainfall prior to sampling or where the station is in close proximity to a freshwater source—such as the Lake Washington Ship Canal. Stations located in these areas consistently failed fecal coliform bacteria standards. This occurred in both 1997 and 1998, although bacteria levels in 1998 were slightly lower. Stations in areas removed from the strong tidal mixing of the open Sound tend to retain freshwater input longer and also have higher bacteria counts. The station near Fauntleroy Cove is in such an area and this station consistently has high values from year to year.

Fecal Contamination in Commercial Shellfish Growing Waters

The Washington State Department of Health (State Health) classifies commercial shellfish beds according to guidelines set by the U.S. Food and Drug Administration's National Shellfish Sanitation Program (NSSP). As of December 1998, more than 100,000 acres of Puget Sound tidelands in 110 growing areas were classified as "approved" or "conditionally approved." Harvest was restricted or prohibited on an additional 16,000 acres.

The guidelines of the NSSP are designed to ensure thorough surveys of harvest areas in order to keep contaminated shellfish out of the market. To be "approved", a growing area must meet minimum standards for water quality and not be subject to contamination that is hazardous to public health.

Compliance with the National Shellfish Sanitation Program's Standards. Before State Health classifies an area, stations within the proposed area are selected and routinely sampled until a minimum of 30 results per station are available. In the interim, State Health conducts a rigorous shoreline survey to locate and evaluate pollution sources. Sources are reported to appropriate agencies for thorough review and action.

Two statistics are calculated from the 30 water sample results. These are compared to the *NSSP Growing Area Standards.* To classify an area, State Health applies the statistics according to the type of pollution in the area: *point sources* (concentrated sources, such as wastewater discharged through a pipe); or *nonpoint sources* (diffuse sources with non-definable pathways, such as failed on-site sewage systems or drainage from pastures). The standards and their application are described below:

1. The *geometric mean* is not to exceed 14 colonies/100 ml of water (applied in all cases).
2. The *90th percentile value* is not to exceed 43 colonies/100 ml of water (applied to areas where only nonpoint sources are present); OR ten percent of results are not to exceed 43 colonies/100 ml of water (applied when one or more point sources are present).

If both statistics meet the criteria *and* the shoreline survey reveals no significant pollutant sources, the area is classified as "approved." If the criteria are not met, but pollution events can be shown to be episodic and predictable (i.e., rain-related runoff, etc.) the area may qualify as "conditionally approved." Additional evaluations are required to determine the limits of the classification. After initial classification, sampling continues and shoreline surveys are periodically repeated. Water quality is monitored monthly in "conditionally approved" areas and six times a year in "approved" areas.

State Health provides an annual analysis of data for each growing area to shellfish growers and local agencies. State Health issues an "early warning" if 90th percentile values at one or more stations in a growing area exceed 30 colonies/100 ml. The 90th percentile is used as the "early warning" statistic because experience has shown this statistic responds more quickly to change than does the geometric mean.

To focus its activities for the PSAMP, State Health has sorted Puget Sound growing areas into two groups. "Core" areas are assessed annually. These areas were selected based on high shellfish harvest, histories of pollution impacts, active remedial action programs and abundant data, and to ensure wide coverage of Puget Sound. "Rotational" areas have minimal pollution and are assessed every three years. Most core areas are sampled 12 times a year; rotational areas are sampled six times a year. The *2000 Puget Sound Update* presents results for all core growing areas, as well as for rotational growing areas in north Puget Sound, the straits of Juan de Fuca and Georgia and the San Juan Islands. Subsequent reports will discuss status and trends at rotational stations in the remainder of the Sound.

State Health scientists' analyses of water quality conditions at shellfish growing areas address two questions:

1. What is the status of fecal coliform contamination relative to State Health's standards and guidelines?
2. Have levels of fecal coliform bacteria changed over time?

To answer these questions for this report, State Health scientists calculated statistics (geometric means and 90th percentile values) for each sampling date starting from the earliest date with the required minimum number of prior results (i.e., 30 previous samplings) forward to March 1999.

Status of Fecal Coliform Contamination in Puget Sound Growing Areas. Figure 23 shows the water quality status of Puget Sound's core and north Sound rotational

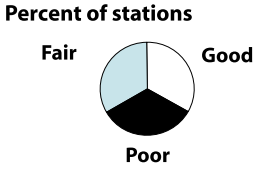
Evaluating fecal coliform data

Ecology scientists take a different approach to evaluating fecal coliform data than do scientists at the Washington State Department of Health and the King County Department of Natural Resources. Ecology scientists compare individual measurements to values specified in the state's water quality standards. King County and the Department of Health compare statistical summaries based on 30 consecutive measurements (typically geometric means and 90th percentile values) to relevant shellfish program or water quality standards. This difference means that Ecology scientists are more likely to characterize an area as having "problem" or "high" levels of contamination.

Statistics on the move

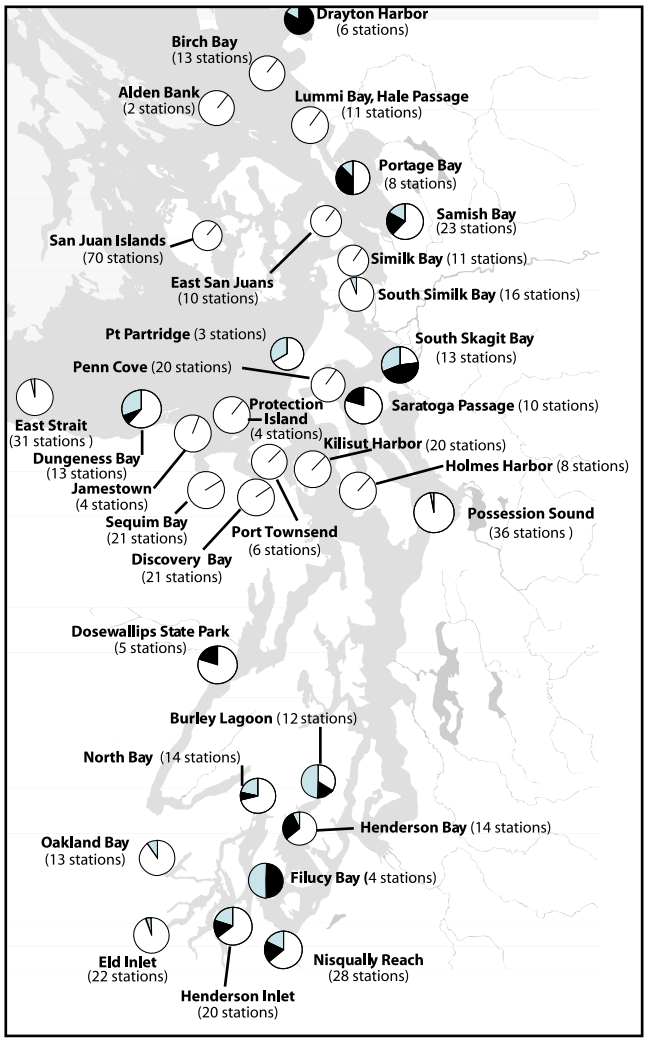
The 30-sample statistics used by the Department of Health are "moving" statistics, where each statistic is updated as new data are available (i.e., the oldest result in the 30-sample set is dropped when a new value is added). This technique reduces the effects of temporal variation inherent in fecal coliform data and thus increases the chances of detecting long-term trends. As a result, the statistics of any particular date actually reflect conditions over a substantial period of time. For example, the statistics for a specific date for a "conditionally approved" station (sampled monthly) actually describe conditions over a 30-month period ending at that date. Statistics from a station in an "approved" area (sampled six times a year) reflect conditions prevailing for five years prior to the sampling date.

Figure 23. Status of fecal coliform contamination at selected shellfish growing areas throughout Puget Sound, 1998-1999.



- **Good** - All statistics less than 30 MPN/100ml
- **Fair** - All statistics less than 43MPN/100 ml, some greater than 30 MPN/100 ml
- **Poor** - Some statistics less than 43 MPN/100 ml

MPN - most probable number of fecal coliform bacteria.



Different measures of fecal contamination in Puget Sound marine waters

Figures 22 and 23 provide slightly different information about fecal contamination of Puget Sound. The distribution of fecal contamination problems presented in Figure 22 reflects the worst conditions observed at open-water stations from October 1995 through September 1997. Figure 23 represents conditions at intertidal shellfish growing areas as indicated by 90th percentile values for sets of 30 samples completed from January 1998 through March 1999. The different time frames may offer a partial explanation. The difference in environment sampled—open water versus intertidal—may also explain some apparent disagreements. For instance, Carr Inlet open waters have low contamination but Filucy Bay, a shellfish growing area along the inlet's southwest shore, is in poor condition. Discrepancies at other areas where assessments do not appear to agree (e.g., Possession Sound and the Strait of Georgia), may be related to different locations of stations within the area, time frames of analyses or approaches used for data analysis (see **Evaluating fecal coliform data** sidebar on page 37).

growing areas. Each pie chart in this figure summarizes the percentage of stations within a growing area that were in good, fair, and poor condition during the period from January 1998 through March 1999. A station was classified as good if no 90th percentile values exceeded the "early-warning" threshold (30 colonies/100ml). A station was termed fair if its maximum 90th percentile value exceeded the "early-warning" threshold, but no 90th percentile values exceeded the NSSP criterion of 43 colonies/100 ml. A station with one or more 90th percentile values above the NSSP criterion was deemed poor.

Among the areas included in this evaluation, the most contaminated areas were Filucy Bay in south Puget Sound (two stations *poor*, two *fair*), Drayton Harbor (five stations *poor;* one *fair*), South Skagit Bay (six stations *poor,* four *fair*, three *good*), and Portage Bay near the mouth of the Nooksack River (three stations *poor*, one *fair,* one *good*). Other areas where one or more stations were identified as poor include Samish Bay, Saratoga Passage, Dungeness Bay, Dosewallips State Park and south Puget Sound's North Bay, Burley Lagoon, Henderson Bay, Nisqually Reach and Henderson Inlet. Other growing areas had stations rated only as good and fair; this includes growing areas in the San Juan Islands, the straits of Juan de Fuca and Georgia, Admiralty Inlet, Penn Cove, Holmes Harbor, Possession Sound, Eld Inlet and Oakland Bay.

The status of any area depends on the magnitude of the sources and the mixing potential of the receiving waters. Certain bathymetric factors (shape of bay, lack of depth, constricted entrance to bay, etc.) and hydrology (ratio of freshwater input to volume of bay, etc.) may limit effective mixing. Frequently, an area's most contaminated stations are located at the head of a poorly flushed inlet (Henderson Inlet, Filucy Bay) or adjacent to a river or stream that carries a fecal load (Dungeness Bay, south Skagit Bay, Samish Bay, Nooksack River). In other areas, it appears that the intensity of human activities within a watershed or along a shoreline threaten water quality and make it increasingly difficult for the waterbody to sustain a safe shellfish harvest.

Have Levels of Fecal Coliform Bacteria Changed Over Time? Temporal trends in fecal

coliform contamination have been evaluated for four growing areas in south Puget Sound. State Health scientists examined time series of 90th percentile values of fecal coliform counts for these areas and performed tests to determine if apparent trends were statistically significant. Increasing trends mean fecal contamination was getting worse. Decreasing trends in contamination mean conditions were getting better.

Eld Inlet. State Health scientists examined 22 stations in Eld Inlet that were sampled continuously from 1988 to 1999. Generally, conditions at these stations improved over time (Figure 24a, page 40). Eighteen stations showed improvement; one station showed worsening conditions, but the 90th percentile values at this location were too low to be of immediate concern. The data indicate that improvements in water quality began in the mid-1990s; this coincides with efforts by the Thurston County Health Division to find and repair on-site sewage systems in beachfront communities and Thurston Conservation District's work with farmers to implement best management practices on their land. Water quality in Eld Inlet was worst at stations located at the upper end (head) of the inlet where fecal sources are strongest and flushing is weakest. The chief source of fecal contamination in Eld Inlet is most likely pasture runoff.

Henderson Inlet. Twenty stations in Henderson Inlet were sampled continuously from 1988 to 1999. As of March 1999, 18 stations showed increasing contamination, one station appeared to be improving and one station showed no significant change (Figure 24b, page 40). The status of five stations worsened since first reported in the 1998 Puget Sound Update. The stations with the worst water quality were in the innermost parts of the inlet where tidal exchange is minimal and pollutant loading is highest. The improved stations are located in the middle of the bay where tidal mixing is higher. Despite the trend of increasing fecal contamination in Henderson Inlet, most of the inlet remains within acceptable limits for shellfish harvest. However, continuing declines in water quality could lead to a downgrade in shellfish harvest classification.

Oakland Bay. Ten stations at Oakland Bay were sampled continuously from 1988 to 1999. The 1998 Puget Sound Update reported that, as of 1996, the status of eight of 10 stations was good, one was fair, and the station near the sewage treatment plant discharge was poor. Data through March 1999 indicate that the poor station improved to fair. The status of the rest of the stations that were evaluated previously remained the same (Figure 24c, page 40).

Three additional Oakland Bay sites that were not available for analysis in 1998 have now been evaluated. These stations are located in the innermost end (head) of the bay, and have been sampled since 1991. The status of the three sites is *good*. However, contamination at two of the three stations appears to be worsening.

Fecal pollution has declined at most stations in the southwest end of Oakland Bay. This improvement is likely due to the continuing renovation of Shelton's municipal sewage system and the control of stormwater contamination during heavy rains. On the other hand, increasing contamination in the north end of the bay probably results from sources on the adjacent shore or in nearby upland drainages. These sources need to be controlled in order to protect the "approved" classification of the north end of Oakland Bay.

Burley Lagoon. Five stations in Burley Lagoon were sampled continuously from early 1990 to 1999. Sampling began at seven more stations in late 1992. Results from the

Sources of fecal contamination

Likely sources of fecal contamination in all areas include failing on-site sewage systems and pasture drainage. Drayton Harbor and Oakland Bay are affected by contaminated urban stormwater among other nonpoint pollution sources. Drayton Harbor is also likely affected by boat wastes and other activity in the vicinity of the Blaine Marina. Major fecal contamination in Portage Bay appears to be attributed primarily to drainage from livestock operations along the Nooksack River. Dosewallips State Park might be partially affected by harbor seals hauling out in sloughs.

Figure 24. Status and trends in fecal coliform contamination in four South Puget Sound shellfish growing areas.

a. **Eld Inlet**

b. **Henderson Inlet**

c. **Oakland Bay**

d. **Burley Lagoon**

Status - from January 1998 through March 1999

☐ **Good -** All statistics less than 30 MPN/100ml

▨ **Fair -** All statistics less than 43MPN/100 ml, some greater than 30 MPN/100 ml

■ **Poor -** Some statistics less than 43 MPN/100 ml

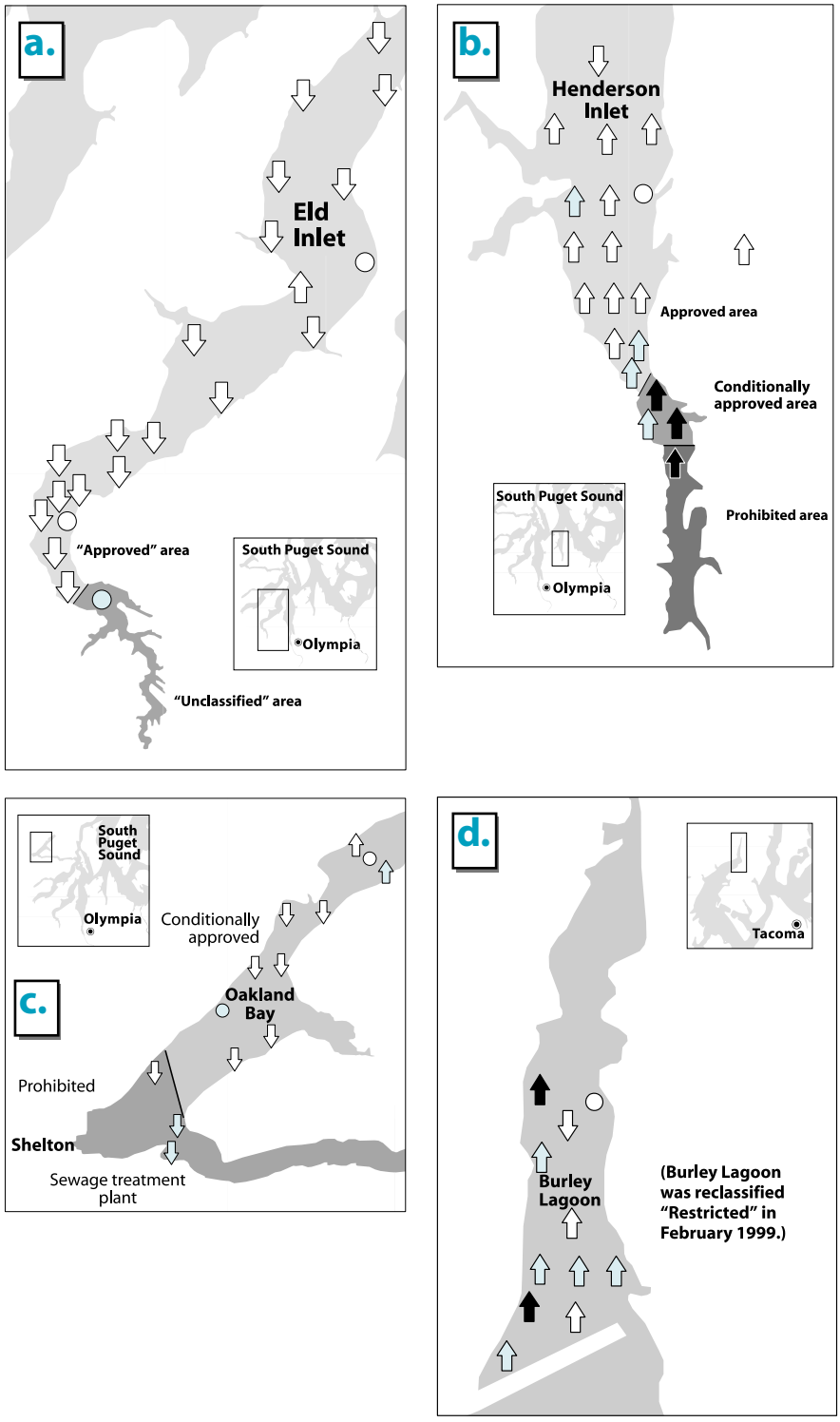
Trends - since January 1995

⇧ **Worse -** Concentrations increasing, conditions getting worse.

○ **Same -** No change observed.

⇩ **Better -** Concentrations decreasing, conditions improving.

MPN - most probable number of fecal coliform bacteria.



five stations with the longer data record were discussed in the *1998 Puget Sound Update;* two of the five stations were in good condition and three were fair. Trends at three stations appeared to be toward improvement. However, conditions in Burley Lagoon deteriorated after 1996. The status of one of the original five stations fell from fair to poor; another went from good to fair. As of March 1999, two of 12 stations in Burley Lagoon were poor; six were fair, and four were good (Figure 24d). Contamination increased at nine of 12 stations.

Remedial programs have been carried out in the Burley Lagoon watershed since the early 1980s. Initial success resulted in an upgrade of part of Burley Lagoon from "restricted" to "conditionally approved" in 1993. When State Health provided early warning of declining water quality in 1997, local health departments and the conservation district renewed programs to locate and control pollution sources. However, it became necessary to return Burley Lagoon to "restricted" classification in February 1999. Nonpoint pollution control programs will need to be intensified if lost ground is to be regained. Pierce and Kitsap counties have signed a Memorandum of Understanding and formed shellfish protection districts to address the problems affecting the Burley watershed.

Summary. The situation in Eld Inlet and Oakland Bay indicates that fecal contamination in Puget Sound bays can be reduced if local citizens and agencies are committed to focused intensive remedial action (both voluntary and regulatory). The situation in Henderson Inlet and Burley Lagoon points to the need for continuous application of rigorously designed and consistently applied nonpoint programs and land-use policies. Finally, monitoring should be continued to assure that control measures are working to preserve water quality in the face of increasing population growth in Puget Sound watersheds and along the Sound's shorelines.

Findings on Nutrients

High nutrient concentrations are rarely directly associated with water quality impairments in the fresh and marine waters of the Puget Sound basin. Table 3 (page 33) shows that only seven Puget Sound waters have been identified as impaired by ammonia or other forms of nitrogen and 20 fresh waters as impaired by phosphorus. However, as discussed on page 31, excess nutrients can increase plankton production and lead to low dissolved oxygen concentrations if the receiving water is nutrient-limited. Table 1 (page 17) identifies 87 Puget Sound waters that are impaired by low dissolved oxygen.

More specific results about nutrient contamination conditions in Puget Sound's fresh and marine waters are presented in this section. Most of the discussion focuses on nitrate. Although nitrate is not toxic to humans at the concentrations measured in Puget Sound's surface waters, it is very important ecologically. Excessive nitrate in the water can increase the likelihood of algae blooms and may promote the growth of undesirable species of algae and plants.

Rivers and Streams

Rivers and streams deliver approximately 10,000 metric tons of inorganic nitrogen and 1,900 metric tons of phosphorus to Puget Sound each year (Inkpen and Embrey, 1998). The U.S. Geological Survey (Inkpen and Embrey, 1998) synthesized nutrient loading information from 1980 to 1993 for rivers and streams in the Puget Sound basin. This evaluation showed that five rivers—the Snohomish, Skagit, Nooksack, Stillaguamish and Puyallup—account for more than 80 percent of the load of inorganic nitrogen delivered from all Puget Sound basin rivers and streams to Puget

Nutrients in fresh and marine waters

Nutrient dynamics are very different in fresh waters than in marine waters. High concentrations of nitrate in freshwater can be used as an indicator of the likelihood that harmful substances are entering the water, because of nitrates' common association with contaminants. Depending on the source, nitrate can be associated with: (1) fertilizers, herbicides or pesticides (lawns or commercial agriculture); (2) industrial and residential chemicals (stormwater runoff from developed areas); and (3) fecal coliform bacteria (livestock wastes, pet wastes, poorly operating on-site sewage systems).

In marine waters, nitrate is naturally very plentiful. Thus, high concentrations of nitrate cannot be used to indicate that human sources are responsible. In marine waters, the presence of ammonium indicates nutrients regenerated from human sources, zooplankton or other marine organisms. Because marine algae can be limited by the availability of nitrogen, information on nitrate and ammonium distributions and dynamics is important to understanding the condition of marine waters, especially when interpreted along with information about water column stratification, dissolved oxygen concentration and phytoplankton abundance (often measured as chlorophyll concentration).

Nutrients from the Pacific Ocean

Approximately 700,000 metric tons of inorganic nitrogen from the Pacific Ocean enter the Strait of Juan de Fuca each year (Harrison et al., 1994). This oceanic supply of nitrogen to Puget Sound far outweighs the contribution of nutrients from the lands (and rivers) of the Puget Sound basin.

Sound. (This study did not estimate the Pacific Ocean's contribution of nutrients to Puget Sound, which is estimated to be many times greater than the contributions from the basin's rivers, or the atmospheric deposition of nutrients directly to the marine waters of the Sound.)

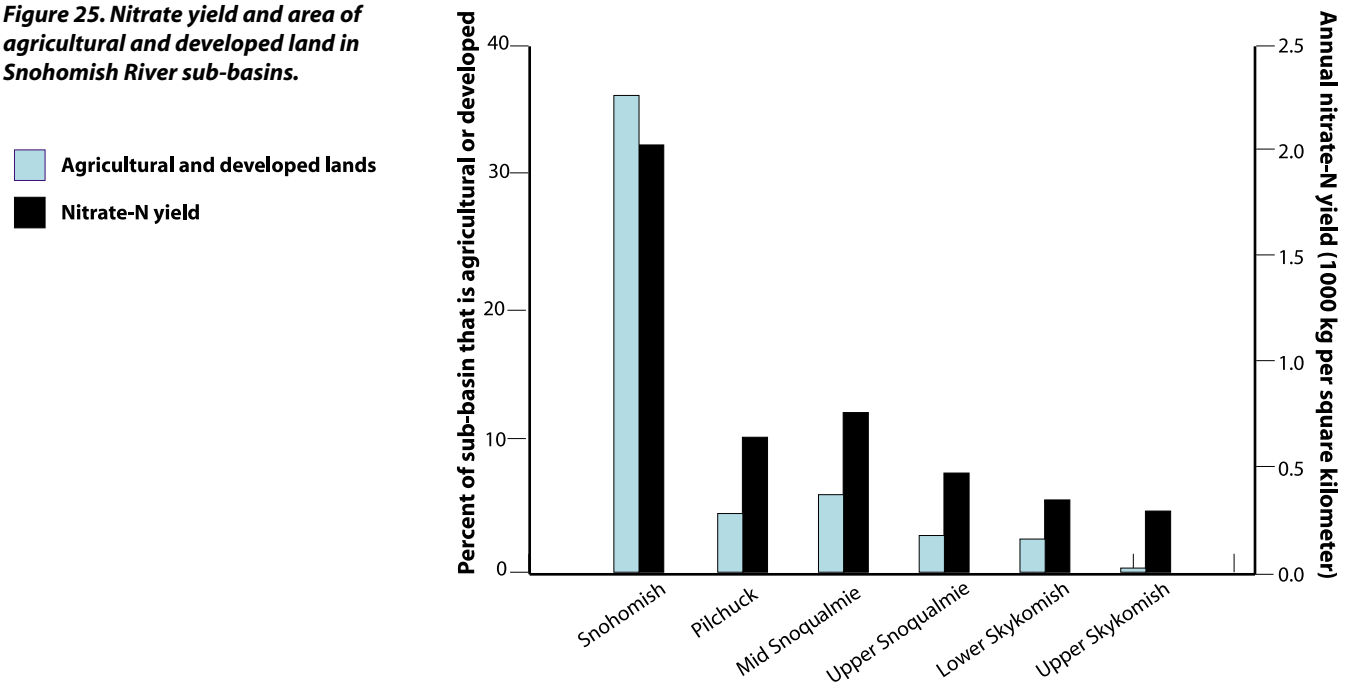
Scientists from the U.S. Geological Survey and elsewhere calculate nutrient contributions not just as loads (i.e., metric tons per year) but also as yields (metric tons/square mile/year) in order to evaluate the intensity of nitrogen contributions independent of river basin size. Using nitrogen yield estimates, scientists from the Geological Survey showed that land use is a major determinant of the nitrogen contributions to Puget Sound watersheds. Of the major rivers that drain to Puget Sound, the Samish River has the highest inorganic nitrogen yield (2.5 metric tons/square mile/year). Other agriculture-dominated basins (Stillaguamish and Nooksack river basins) also have relatively high yields (1.6 to 1.8 metric tons/square mile/year). The Snohomish River basin, with mixed land uses (urban and agriculture), has a relatively high yield (1.6 metric tons/square mile/year).

Department of Ecology scientists have used ambient monitoring data to perform a more focused evaluation of the relationship between land use and nutrient contributions in the Snohomish River basin. As mentioned above, land use in the Snohomish River basin is quite varied; the basin is dominated by forests at higher elevations and a mix of agriculture and urban/suburban development in the lower elevations.

Ecology's analysis provides additional evidence that nitrate yields are higher in sub-basins with a higher proportion of land in agriculture or urban/suburban development (Figure 25). Note that the upper and lower Skykomish and upper Snoqualmie sub-basins, which have lesser degrees of agriculture or other development, have the lowest nitrate yields.

The causes of higher nitrogen yields from agricultural and developed lands are probably a combination of fertilizer application (both residential and commercial)

Figure 25. Nitrate yield and area of agricultural and developed land in Snohomish River sub-basins.



sewage treatment plant effluent, stormwater runoff and animal waste. Animal manure, agricultural fertilizers and atmospheric deposition have been identified as the three largest sources of nitrogen contributing to the lands of the Puget Sound basin (Inkpen and Embrey, 1998).

Marine Waters

Nutrient concentrations measured in Puget Sound represent the balance of nutrients that enter and leave the ecosystem. Nutrients enter Puget Sound from the ocean, fresh water and human-caused sources. A major pathway for their removal is photosynthesis. Phytoplankton, seaweeds, eelgrass and salt marsh plants all use nutrients as they produce new organic matter through photosynthesis.

At the heart of scientists' concerns about nutrient input to Puget Sound is the potential for excessive production by phytoplankton or other photosynthesizers and the effects of this productivity on ecosystem balances. Nutrient inputs to Puget Sound's marine waters can cause a problem when marine water conditions are such that nutrient additions spur additional productivity (i.e., in stratified waters where photosynthesis is nutrient limited).

Existing monitoring is not sufficient to describe areas of excess nutrient loadings to Puget Sound's marine waters. Therefore, the evaluation of nutrients in Puget Sound marine waters focuses on evaluating how the productivity of waters in various portions of Puget Sound might be affected by increased nutrient loading.

Scientists from Ecology's marine water monitoring program have identified a number of areas of Puget Sound where conditions reflect the potential for nutrient-related water quality degradation. Figure 26 summarizes nutrient conditions measured by scientists at stations monitored in wateryears 1996 and 1997. Each station is represented by a two-sided symbol, where the left side describes dissolved inorganic nitrogen (DIN) conditions and the right side describes ammonium conditions.

Low or non-detectable levels of dissolved inorganic nitrogen indicate that nutrient availability may be limiting phytoplankton productivity. Ecology scientists categorize their monitoring stations by the duration of non-detectable levels of dissolved inorganic nitrogen. Longer durations

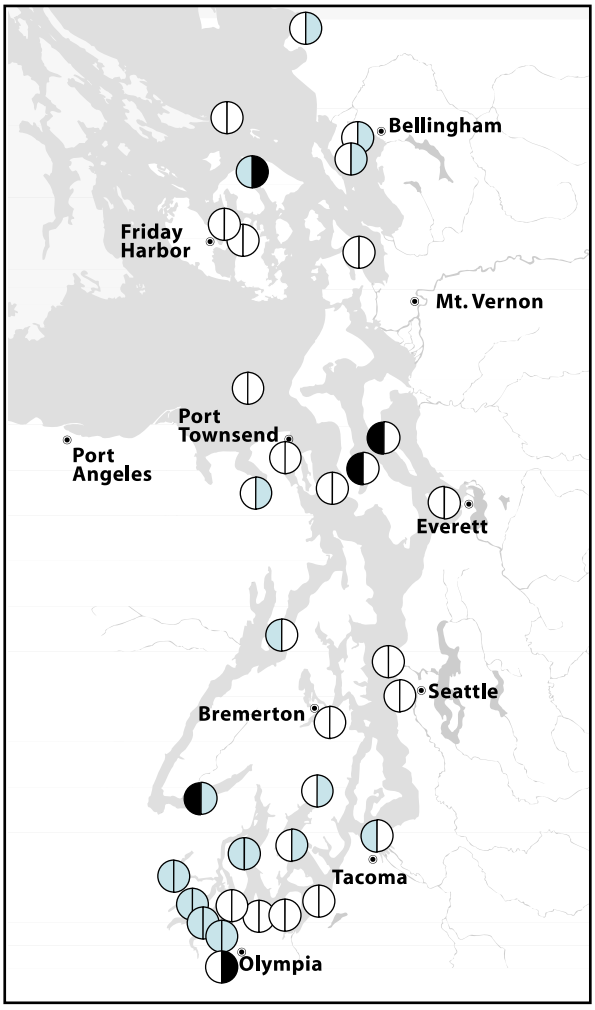


Figure 26. Nutrient conditions at Puget Sound open-water monitoring stations, 1996-1997.

Dissolved inorganic nitrogen (DIN):

- **DIN not detectable in surface waters for five or more consecutive months.**
- **DIN not detectable in surface waters for three or four consecutive months.**
- **DIN not detectable in surface waters for less than two consecutive months.**

Ammonium:

- **Maximum ammonium greater than 0.14 mg/L**
- **Maximum ammonium 0.07 to 0.14 mg/L**
- **Maximum ammonium no more than 0.07 mg/L**

Nutrient-related problems in Puget Sound are poorly characterized

A draw-back to Ecology's approach to indicating nutrient-related problems in Puget Sound's marine waters is that it only identifies areas that are sensitive to excessive nutrient loading, but does not identify areas currently affected by increased loadings of nutrients. Based on nutrient concentrations alone, these latter areas would be indistinguishable from areas with mixed water columns and a steady supply of nitrogen from the ocean. However, such areas could presumably be identified from other indicators presented in this Update (e.g., low dissolved oxygen, as discussed on pages 21-22).

indicate greater evidence of nutrient-limited productivity and, therefore, sensitivity to excessive nutrient loading. For wateryears 1996 and 1997, only lower Hood Canal, Holmes Harbor and Saratoga Passage had less than detectable concentrations of dissolved inorganic nitrogen for five or more consecutive months. A number of other areas, including East Sound (Orcas Island), upper Hood Canal, Oakland Bay and Case, Totten, Eld and Budd inlets, had non-detectable levels for three or four consecutive months.

Dissolved inorganic nitrogen conditions measured in 1996 and 1997 are generally consistent with those seen in the longer record (back to 1993). The largest difference is seen at Possession Sound (near the mouth of the Snohomish River) where recent data indicate that dissolved inorganic nitrogen is prevalent, while the longer data record shows periods of non-detectable levels of five months or more.

The right sides of the symbols in Figure 26 show the occurrence of elevated levels of ammonium, as measured by Ecology scientists during wateryears 1996 and 1997. High ammonium concentrations indicate the presence of an ammonia source, which could be a sewage input or concentrations of zooplankton. Therefore, high ammonium concentrations provide evidence of a human loading of nutrients (eutrophication), a high concentration of phytoplankton upon which zooplankton might be grazing, or the presence of concentrations of fish, seals, whales or other marine life.

During wateryears 1996 and 1997, high ammonium concentrations (greater than 0.14 mg/L) were observed at East Sound and inner Budd Inlet. Moderately high concentrations were more widespread, occurring at Drayton Harbor, Bellingham Bay, Discovery Bay, southern Hood Canal, Commencement Bay, Oakland Bay and Carr, Case, Totten, Eld and outer Budd inlets. The results for 1996 and 1997 are generally consistent with the longer data record, except that recent results show lower concentrations at Possession Sound, Elliott Bay and Sinclair Inlet.

Table 4 summarizes multiple lines of evidence to identify areas of Puget Sound that appear most sensitive to water quality problems associated with eutrophication. This table was constructed based on Ecology scientists' review of their data on dissolved oxygen conditions, stratification intensity and nutrient concentrations from 1993 to 1998 (Newton, personal communication). This analysis indicates that the areas of greatest concern include southern Hood Canal, Budd Inlet and Penn Cove. Nutrient discharges to other areas listed in Table 4 should also be evaluated, though the evidence for the possibility of eutrophication-related problems at these other areas is not quite as great.

This table includes five locations that were not previously identified as potential problem areas: Bellingham Bay, Holmes Harbor, Carr Inlet, Drayton Harbor and Skagit Bay. Ecology's evaluations of Quartermaster Harbor and Discovery Bays are much different than in previous years, reflecting information from new monitoring stations that show different results than the more open-water stations used previously.

King County monitors nutrient concentrations at four offshore stations in King County waters located in the central Puget Sound basin. Monthly samples are collected at depth levels ranging from one meter to 200 meters.

Seasonal patterns of ammonium detection reflect the seasonal pattern of phytoplankton biomass as indicated by chlorophyll-a, with peaks occurring in summer and fall. This may be due to an increase in zooplankton grazing activity. An anomalously high value of ammonium was measured at the West Point Treatment

Location	Dissolved Oxygen (1)	Stratification Intensity	Nutrient Conditions	
			DIN (2)	NH4+ (3)
Southern Hood Canal	Very Low	Persistent	Low	Moderate
Budd Inlet	Very Low	Persistent	Low	Moderate
Penn Cove	Very Low	Persistent	Low	Moderate
East Sound	Very Low	Seasonal	Low	High
Discovery Bay	Very Low	Seasonal		Moderate
Quartermaster Harbor	Very Low	Seasonal		Moderate
Possession Sound	Low	Persistent	Low	Moderate
Bellingham Bay	Low	Persistent	Moderate	Moderate
Commencement Bay	Low	Persistent	Moderate	Moderate
Holmes Harbor	Low	Persistent	Low	
Saratoga Passage	Low	Persistent	Low	
Port Susan	Low	Persistent	Low	
Elliott Bay	Low	Persistent		Moderate
Carr Inlet	Low	Seasonal		Moderate
Drayton Harbor	Low	Seasonal		Moderate
Skagit Bay	Low	Persistent		
Sinclair Inlet		Persistent	Moderate	Moderate
Eld Inlet		Seasonal	Moderate	Moderate
Case Inlet		Seasonal	Moderate	Moderate
Oakland Bay		Episodic	Moderate	Moderate
Totten Inlet		Episodic	Moderate	Moderate
Dyes Inlet		Seasonal	Moderate	
Sequim Bay		Seasonal	Moderate	

Table 4. Areas of Puget Sound where eutrophication may be a concern based on data from 1993-1998.

1. Ecology scientists noted dissolved oxygen as "very low" if any measurement was below 2 mg/L; as "low" if any measurement was below 5 mg/L but none were below 2 mg/L. Low and very low dissolved oxygen can stress and kill marine organisms. Dissolved oxygen cells are blank where no measurements below 5 mg/L were recorded.
2. DIN = dissolved inorganic nitrogen; "low" indicates DIN was not detectable down to 10 m for three or more consecutive months; "moderate" indicates that DIN was not detectable at the surface for three or more consecutive months.
3. NH_4^+ = ammonium; "high" indicates at least one measurement above 0.14 mg/L; "moderate" indicates at least one measurement above 0.07 mgL but none above 0.14 mg/L.

Plant outfall in early October 1998. This may have been due to a temporary shut-down of the treatment facility and a release of untreated sewage on October 12th. Ammonium was rarely detected in samples collected during the winter of 1997-98, including in samples from West Point.

In 1997 and 1998, consistent patterns in nitrite and nitrate concentrations were observed at all stations.

- Nitrite and nitrate concentrations were low when ammonium concentrations were high.
- Minimum concentrations of nitrite and nitrate occurred in summer and fall.
- Nitrite and nitrate concentrations were inversely proportional to chlorophyll-a concentrations.

These relationships all point to the effective removal of nutrients from the water column by phytoplankton.

In 1998 and 1999, nutrient samples were collected at five nearshore stations. There was no apparent difference in nutrient concentrations between nearshore and offshore stations, with the exception of ammonium detected at West Point but not at nearshore stations in the area.

Acting on the Findings

Recent information about pathogen and nutrient problems in Puget Sound's rivers and streams and in its marine waters suggests a number of follow up actions:

- The Department of Ecology should continue (and emphasize) its efforts to develop clean-up plans (also known as total maximum daily loads or TMDLs) for waters that are impaired by fecal coliform contamination. Monitoring program results can be used to set priorities for these efforts. The clean-up plans should provide the technical basis for watershed and shoreline improvements that will lead to water quality improvements.

- Relationships between land use (especially the development of shorelines and watersheds) and water quality in nearby shellfish growing areas should be further analyzed to help resource managers, land use planners and public health officials understand the critical limits that might affect commercial and recreational shellfish harvest in Puget Sound.

- Increasing fecal contamination in Henderson Inlet in south Puget Sound should be investigated and pollution sources controlled in an effort to prevent a downgrade of the area's shellfish harvest classification.

- Decisions about the discharge of nutrients to Puget Sound from point and nonpoint sources should incorporate an understanding of the local marine area's sensitivity to nutrient-related water quality degradation. Areas of Puget Sound shown to be sensitive to eutrophication should be managed accordingly.

- Areas of Puget Sound that are sensitive to nutrient-related water quality degradation should be investigated further to characterize nutrient loading and cycling.